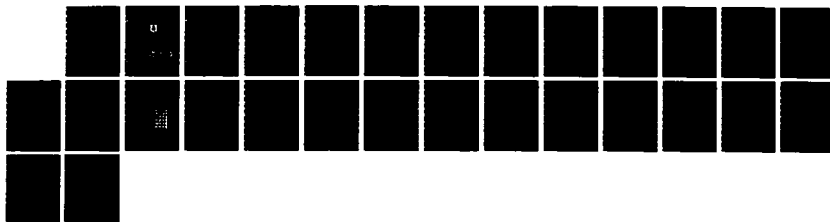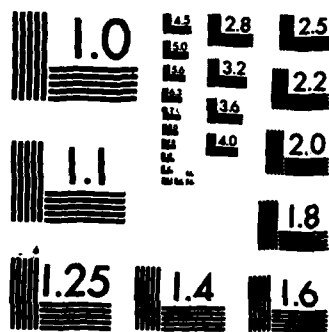AD-A140 007   CALCULATION OF PENETRATING RADIATION OF THE AIR DEFENSE   1/1
STRUCTURE(U) FOREIGN TECHNOLOGY DIV WRIGHT-PATTERSON
AFB OH   K NING 26 MAR 84 FTD-ID(RS)T-0113-84

UNCLASSIFIED   F/G 18/6   NL

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU-OF STANDARDS-1963-A

FOREIGN TECHNOLOGY DIVISION

CALCULATION OF PENETRATING RADIATION OF THE AIR
DEFENSE STRUCTURE

by

Kang Ning

DTIC
ELECTE
APR 10 1984
S   D
B

AD A140007

DTIC FILE COPY

84 04 09 188

EDITED TRANSLATION

CALCULATION OF PENETRATING RADIATION OF THE AIR DEFENSE
STRUCTURE

By: Kang/Ning

English pages: 24

GRAPHICS DISCLAIMER

All figures, graphics, tables, equations, etc. merged into this
translation were extracted from the best quality copy available.

Accession For		
NTIS GRA&I	✓	
DTIC TAB	☐	
Unannounced	☐	
Justification		
By		
Distribution/		
Availability Codes		
Dist	Avail and/or Special	
A-1		

DTIC COPY INSPECTED

i

CALCULATION OF PENETRATING RADIATION OF THE AIR DEFENSE STRUCTURE

Kang Ning

The fundamental factors that kill and injure people in a nuclear detonation are shock wave, photo-radiation and nuclear radiation. During a detonation of a nuclear device at a height lower than 30 kilometers in the atmosphere, the energy of photo-radiation occupies 35 percent of the detonation; however, 50 percent of the nuclear detonation is expended in forming a shock wave. The remaining 15 percent of the energy is released in the form of nuclear radiation. Although the energy of nuclear radiation occupies a small portion of the total energy of detonation, the radiation has very high penetrating power. Therefore, at a relatively great distance from the detonation center, even the killing and/or injuring function may exist inside a shelter. Therefore, the study of protection from nuclear detonation is a difficult task for technical personnel in underground construction.

The calculation of underground construction providing protection from nuclear radiation includes three parts: the top cover, wall and hole opening. It is required that the incident dosage does not exceed the allowable dosage of 50 roentgens. However, in the present papers, there is a lack of clarified description on this problem; in addition, points in the calculations still have room for further discussion. Mostly, only incidence of nuclear radiation along the normal direction is considered, without considering oblique-direction nuclear radiation. Although in some cases oblique incidence is considered, oblique

1

incidence after the radioactive cloud rises is not considered. For the afore-
mentioned situations, this paper presents the problem of protection from
nuclear radiation for underground construction. Readers' corrections are
welcomed.

I. Characteristics of Nuclear Radiation (Penetrating Radiation) and Decay of
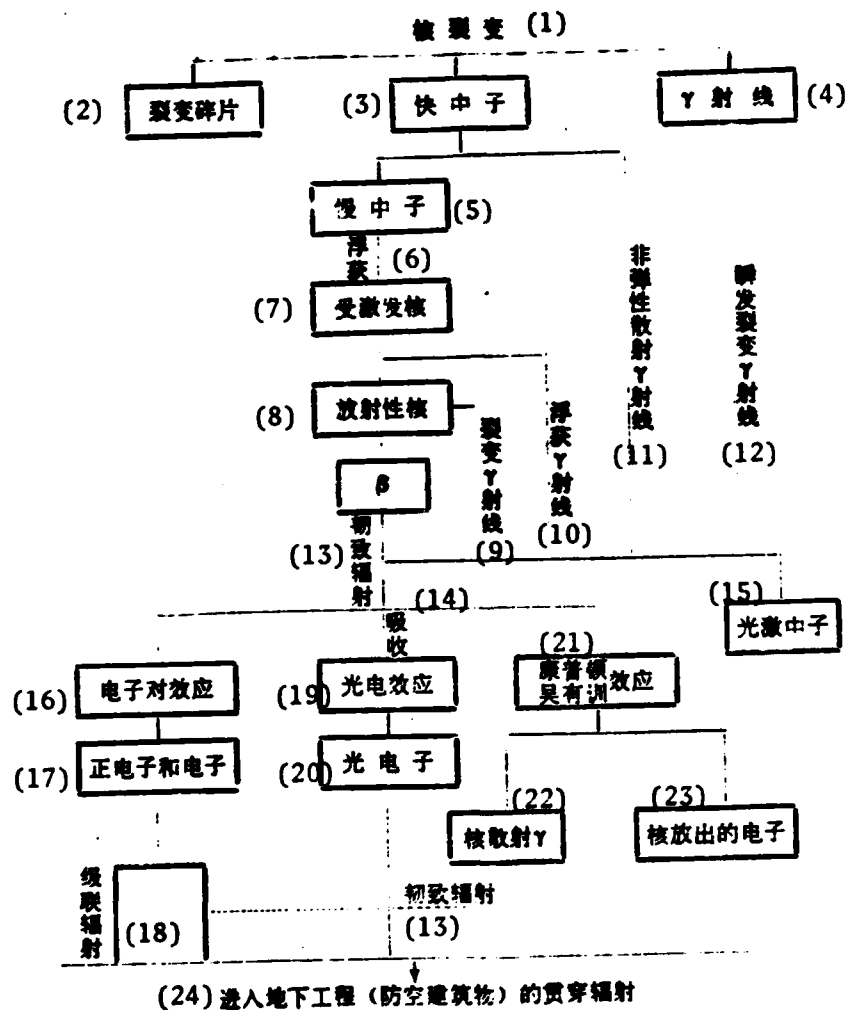Radiation

1. General characteristics of penetrating radiation

Nuclear radiation is composed of alpha particles, beta particles, gamma rays
and three types of neutron streams. The effective range of alpha particles in
the atmosphere is only several centimeters; the effective range of beta particles
(high-speed electrons) is still only several meters in the atmosphere. The range
of gamma rays (high-energy electromagnetic radiation, similar to X-rays) is as
far as thousands of meters in the atmosphere; the range of neutrons (particles
released after nuclear fission and/or fusion) is hundreds of meters. It is
apparent that the calculation of penetrating radiation is mainly the study of
gamma rays and calculation of the neutron stream.

However, in actual structural calculations, we do not consider all gamma rays
and neutron streams released following the detonation of a nuclear weapon. For
detonation of fission bombs, according to the emission time the gamma radia-
tion is divided into instantaneous gamma radiation, short lived gamma radiation,
and gamma radiation lasting a number of seconds. As revealed in studies, the
major radiation dosage in the detonation area is radiation lasting a number of
seconds, and next important is the short lived radiation. The longest acting
time of these radiations on the ground target is 15 to 20 seconds. Neutrons
from nuclear fission can be divided into fast neutrons, medium-speed neutrons
and slow neutrons. Since the dosage of slow neutrons is smaller than that of
fast neutrons, and at the same time neutrons are released in a relatively short
period of time, the casualty function of neutrons is generally caused by fast
neutrons. It is apparent that the calculation for a protective structure only
considers gamma radiation lasting a number of seconds, short lived gamma radia-
tion and fast neutrons. However, the penetrating radiation dosage released by

a fusion bomb (thermonuclear bomb) includes some ultra high-speed neutrons beside gamma rays and high-speed neutrons.

2. Decay process of penetrating radiation (refer to two flow charts in the following)

核 裂 变 (1)

(2) 裂变碎片   (3) 快 中 子   γ 射 线 (4)

慢 中 子 (5)

浮获 (6)

(7) 受激发核

(8) 放射性核

非弹性散射γ射线 (11)   瞬发裂变γ射线 (12)

β

(13) 初袭辐射   裂变γ射线 (9)   浮获γ射线 (10)

(14) 吸收   (15) 光激中子

(16) 电子对效应   (19) 光电效应   (21) 康普顿昊育测效应

(17) 正电子和电子   (20) 光 电 子

(22) 核散射γ   (23) 核放出的电子

级联辐射 (18)   初软辐射 (13)

(24) 进入地下工程（防空建筑物）的贯穿辐射

Key: (1) Nuclear fission; (2) Fission fragments; (3) Fast neutrons; (4) Gamma rays; (5) Slow neutrons; (6) Capture; (7) Excited nucleus; (8) Radioactive nucleus; (9) Fission gamma rays; (10) Captured gamma rays; (11) Gamma rays with inelastic scattering; (12) Instantaneous fission gamma rays; (13) Residual radiation; (14) Absorption; (15) Photo-excited neutrons; (16) Electron-pair effect; (17) Positrons and

[Key continued on following page]   3

electrons; (18) Cascade radiation; (19) Photoelectric effect; (20) Photoelectrons; (21) Compton-Wu (Youxun) effect; (22) Nuclear scattering gamma radiation; (23) Nuclear released electrons; (24) Penetrating radiation entering underground works (air-defense structure).
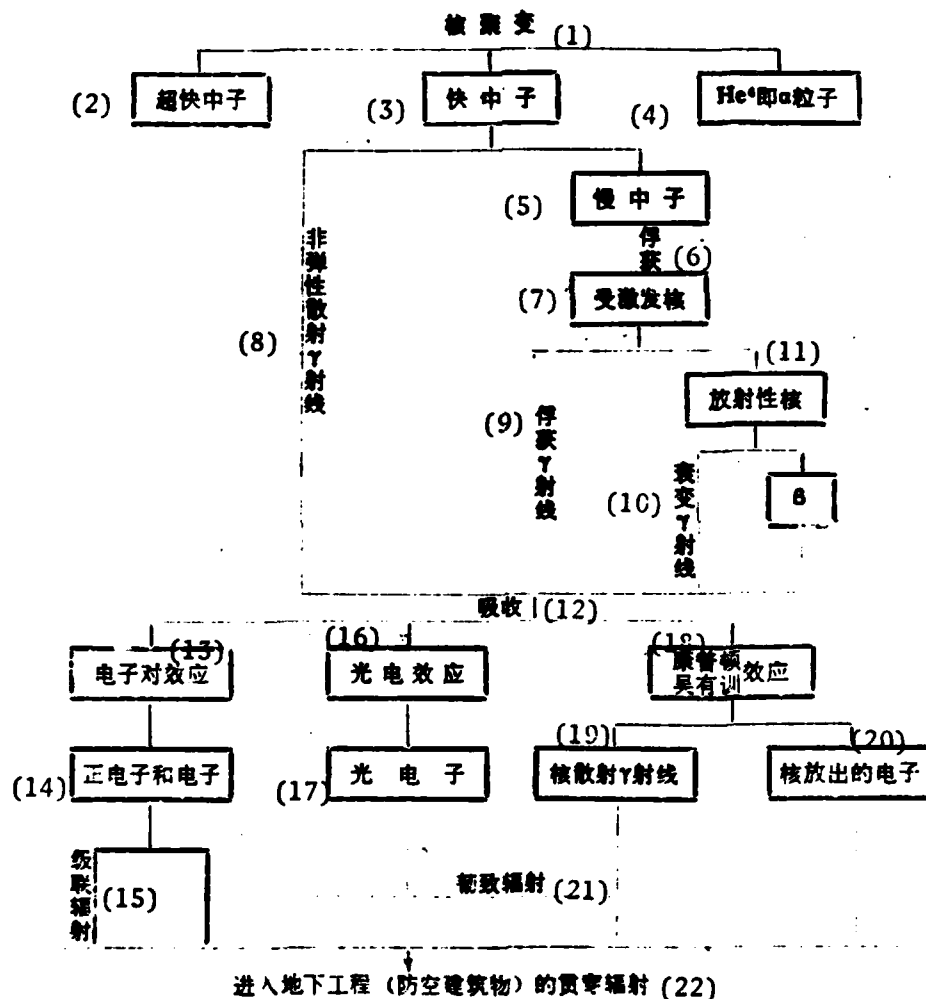
Key: (1) Nuclear fusion; (2) Ultra high-speed neutrons; (3) Fast neutrons; (4) He^4 (alpha particles); (5) Slow neutrons; (6) Capture; (7) Excited nucleus; (8) Gamma rays with inelastic scattering; (9) Captured gamma rays; (10) Decayed gamma rays; (11) Radioactive nucleus; (12) Absorption; (13) Electron-pair effect; (14) Positrons and electrons; (15) Cascade radiation; (16) Photoelectric effect; (17) Photo-electrons; (18) Compton-Wu (Youxun) effect; (19) Nuclear

scattering gamma rays; (20) Nuclear released electrons; (21) Residual radiation; (22) Penetrating radiation entering underground works (air-defense structure).

II. Calculation of Protection by Underground Works From Gamma Rays

1. Calculation of protective layer (including cover and wall)

When the gamma rays transmitted from the detonation center to underground works pass through the protective layer to enter the underground works, the intensity of the gamma rays decays continuously because of mutual actions among atoms (in the forms of photoelectric absorption, Compton-Wu (Yunxun) scattering and electron-positron pair). Refer to YUANZI BAOZHA DI GAMMA FUSHE [GAMMA RADIATION FROM ATOMIC DETONATION], page 33. When gamma rays have a vertical incidence, the calculation formula is

$$D_\gamma = D_{\gamma 0} K = a_\gamma D_{\gamma 0} e^{-\mu x} \qquad (1)$$

In the equation, D_γ is the dosage (in roentgens) of gamma rays after passing through the protective layer; $D_{\gamma 0}$ is the dosage (in roentgens) of incident gamma rays; e is the base of the natural logarithm; μ is the total decay coefficient (obtained from Table 1) of gamma radiation exerted by the protective layer; a_γ is the decay coefficient of the softest scattering of the protective layer (the value of the decay coefficient can be obtained from Fig. 1); K is the decay coefficient of the dosage of gamma radiation exerted by the protective layer; and x is the thickness (in cm) of the protective layer.

In the situation of oblique incidence, decay of gamma ray intensity is faster than in the normal direction (vertical) incidence through the protective layer, because the passage of the gamma rays is longer; in other words, the thickness of the protective layer along the direction of the ray beam is relatively increased. From O. I. Lieyisiji [transliteration of Russian name], at that time the dosage decay coefficient K_γ can be expressed by the following equation:

Table 1.

(a) 材料名称	(b) 有效衰减系数 μ (厘米$^{-1}$)	
	ε_0 = 1兆电子伏特	ε_0 = 2.5兆电子伏特 (c)
(d) 木材	0.033 (c)	0.027 (c)
(e) 土	0.08	0.05
(f) 混凝土	0.11	0.07
(g) 铁	0.33	0.25
(h) 铅	0.80	0.39
附 注 (i)	ε_0—光子能量 (j)	

Key: (a) Material; (b) Effective decay coefficient
μ (cm^{-1}); (c) Electron megavolts; (d) Wood; (e) Earth;
(f) Concrete; (g) Iron; (h) Lead; (i) Remarks; (j)
Photon energy.

$$K_\gamma(l,\varphi,\varepsilon_0) = a(\varphi,\varepsilon_0,K)K_\gamma(l,\varepsilon_0) \qquad (2)$$

In the equation, $K_\gamma(l, \varepsilon_0)$ is the dosage decay coefficient of gamma rays (with
ε_0 as the photon energy) while passing through a protective layer (with thickness
l) along the normal direction; K is the calculated as $K=e^{-\mu x}=2^{-x/d}$; and $a(\phi, \varepsilon_0, K)$
is the coefficient of oblique incidence (refer to Table 2) when the incident
angle is between 0° and 30°. $a(\phi, \varepsilon_0)=1$; i.e., the oblique thickness of the
protective layer can be considered the same as the vertical thickness.

As is well known, the radioactive cloud (major radiation source of gamma
radiation) formed after a nuclear detonation rises with a definite speed (v_c=72
to 100 m/sec). The radiation dosage of gamma rays acting on a protective layer
of fortification and the minimum thickness of (radiation passing through) the
protective layer vary continuously. For different oblique angles, there is a
different function of the protective layer. The smaller the oblique angle, the
greater is the relative thickness of the covering, and the thinner the relative
thickness of the wall. Conversely, the greater the oblique angle, the thinner

6

is the relative thickness of the covering and the greater the relative thickness of the wall (Fig. 2).

Table 2. Coefficient $a_1(\phi, \epsilon_o, K)$ of oblique incidence.

K \ tgφ / N	0	0.5	0.07	1.0	1.2	1.5	1.73	2.00	2.715
	0	1.12	1.2	1.41	1.56	1.8	2.00	2.25	2.925
10^{-1}	1	1	1.00	1.00	1.00	1.00	1.00	1.05	1.20
10^{-2}	1	1	1.01	1.29	1.40	1.70	1.90	2.05	2.50
10^{-3}	1	1	1.03	1.72	2.00	2.50	3.50	4.10	5.60
10^{-4}	1	1	1.46	2.36	2.90	4.80	6.30	8.00	12.8
10^{-5}	1	1	1.80	3.40	4.30	8.30	11.4	15.4	26.5
10^{-6}	1	1.0	2.30	5.60	6.50	14.4	20.4	30.0	57.0
10^{-7}	1	1	3.20	7.40	10.0	21.9	36.4	62.0	132
10^{-8}	1	1	4.50	11.0	15.5	43.6	65.0	132	317
10^{-9}	1	1	6.90	17.4	24.0	76.0	116	211	770
10^{-10}	1	1	10.0	26.7	37.0	132	205	652	1880
10^{-11}	1	1	15.5	41.0	57.0	23.0	362	1500	4600
10^{-12}	1	1	24.4	75.0	88	402	642	3360	11200
10^{-13}	1	1	38.7	107	136	704	1140	8050	27200
10^{-14}	1	1	65.7	150	210	1240	20400	23000	65800

备 考
(a)

1. $N_i = \dfrac{1}{\cos\theta}$

(b) 本表系根据 "原子爆炸γ辐射" 一书第21表，并 "采用" 水平防护层

2. 对贯穿辐射剂量衰减的计算，对φ进行延伸计算得出(c)

Key: (a) Remarks; (b) This table is based on Table 21 of YUANZI BAOZHA GAMMA FUSHE [GAMMA RADIATION OF ATOMIC DETONATION], and "uses" a horizontal protective layer; (c) In the calculation of dosage decay of penetrating radiation, ϕ is calculated by extrapolation.

At that time, the dosage of gamma radiation decayed after passing through the protecti· layer can be calculated according to the following equation:
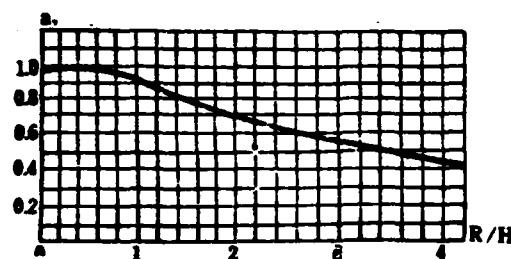
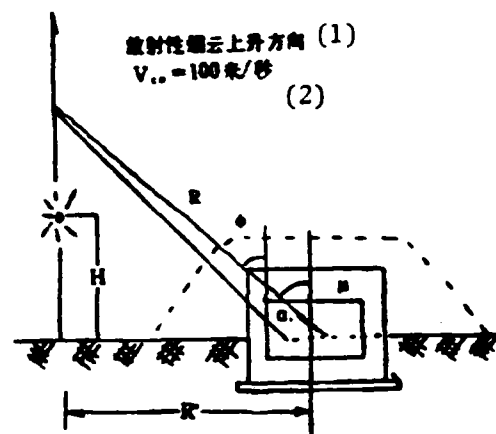Fig. 1. Variation of a_γ of earth and concrete with R/H.

Fig. 2. ai (oblique angle); ϕ (incident angle).
Key: (1) Rising direction of radioactive cloud; (2) m/sec.

$$D_r = \sum_{i=1}^{n} \frac{a_r D_{r0}}{n} a_i(\varphi_r, \varepsilon_0, K)e^{-\mu x_i} \qquad (8)$$

Expressed with half-value thickness:

$$D_r = \frac{a_r D_{r0}}{n} \sum a_i(\varphi, \varepsilon_0, K)2^{-x_i/d} \qquad (4)$$

If we simplify Eq. (4) into a form similar to incidence along the normal direction:

$$D_r = a_r b D_{r0} 2^{-h/d} \qquad (4')$$

In the equation, d is the half-value thickness of the material (Table 3); and b is the decay coefficient of oblique incidence. $b = \frac{1}{n}\sum_{i=1}^{n} a_i(\varphi \varepsilon_0, K)2^{(H-x_i)/d}$.

Tables 4 and 5 show the oblique-direction decay coefficient of concrete (reinforced concrete) to an atomic bomb; x_i is the oblique thickness of the protective layer in different time intervals.

For cover:
$$x_i = \frac{H_o}{\cos\varphi_i} = \frac{H_o \sqrt{(H + v_{cp}t_i)^2 + R'^2}}{H + v_{cp}t_i} \qquad (5)$$

For wall:
$$x_i = \frac{H_o}{\sin\varphi_i} = \frac{H_{cr}\sqrt{(H - v_{cp}t_i)^2 + R'^2}}{R'} \qquad (6)$$

8

In the equations, H_n is the thickness (in meters) of the cover protective layer; H_{CT} is the thickness (in meters) of the wall protective layer; H is the altitude (in meters) of the atomic detonation; R' is the distance (in meters) from the underground works to the projecting point of the detonation center; ϕ_i, ϕ_{i-1}--t_i, t_{i-1} is the intersection angle between the instantaneous incident gamma rays and the normal line of the protective layer; and t_i, t_{i-1} indicate time. The action time on the underground works by gamma rays is divided into n sectors. $t_i(t_{i-1})$ is the time duration between the instant at the end of the i(i-1)-th sector and the instant that the atomic bomb begins to detonate. This time duration is approximately 15 seconds. Refer to Table 6 for dose percentages released at various instants.

Table 3. Half-value thickness of materials.

(a) 材料名称	单位体积重量 (克/厘米) (b)	半值削弱厚度 d_a (c)
(d) 雪	/	50
(e) 木材	0.7	30
(f) 冰	1.0	23
(g) 土壤、砂	1.7	14
(h) 风化卵石、软页岩	2.0	12
(i) 砂质页岩、片状砂岩	2.4	10
(j) 花岗岩、片麻岩	2.7	10
(k) 砌砌体	1.5	15
(l) 混凝土	2.8	10
(m) 钢筋混凝土	2.4	10
(n) 铁	7.8	2.8

Table 4. Oblique-direction decay coefficient b with cover.

H_a/d_a \ R_1/H	0.5	1.0	1.5	2.0
8	0.710	0.390	0.220	0.14
15	0.500	0.250	0.090	0.065
20	1.460	0.200	0.061	0.052

Note: For Tables 3 and 4, data are calculated for q equal to 8000 tons, and H equal to 400 meters altitude with atmospheric detonation of the atomic bomb. If q is greater than [sic] 8000 tons, application of data in both tables provides higher factor of safety.

Key: (a) Material; (b) Weight of unit volume (grams/cubic centimeter); (c) Half-value weakened thickness; (d) Snow; (e) Wood; (f) Ice; (g) Soil, sand; (h) Weathered gravel, soft shale; (i) Sandy shale, schistose sandstone; (j) Granite, gneiss; (k) Dressed masonry; (l) Concrete; (m) Reinforced concrete; (n) Iron.

Table 5. Oblique-direction decay coefficient b with wall.

H/R_1 \ Hc_γ/dn	0.5	0.67	1.0	2.0
8	0.48	0.39	0.17	0.030
10	0.40	0.30	0.13	0.015
12	0.33	0.25	0.093	0.0067
15	0.30	0.19	0.61	0.0036
18.5	0.19	0.16	0.038	0.00071
20	0.18	0.12	0.033	0.00056

Table 6. Radiation dosages released at various instants with atmospheric detonation of an atomic bomb.

(a) 防护层种类	(b) 对 墙 壁					(c) 对 掩 盖				
(d) 辐射设百分比 均算时间(秒)　(e) 当量(千吨) (f) 辐射百分比%	8	20	30	150	5000	8	20	30	150	5000
0—20	0	0	0	0	0.4	0.025	0.03	0.04	1.35	2.2
20—40	0.025	0.03	0.40	0.35	2.2	0.13	0.16	0.28	1.2	3.8
40—60	0.13	0.16	1.28	1.2	3.8	0.55	0.7	1.0	30	50
60—80	0.55	0.7	1.0	3.0	5.0	2.0	2.3	3.0	5.0	7.5
80—100	2.0	2.3	3	5	7.5	15	15	15	15	20

Key: (a) Types of protective layer; (b) For wall; (c) For cover; (d) Mean calculated time (in seconds) of the assumed percentage of radiation; (e) TNT equivalent (in kilotons); (f) Radiation percentage.

III. Calculation Examples of Gamma Ray Defense Provided by Air Defense Structure

There is an annex type air defense structure (six stories with 3.2 meters as the height of a story); the TNT equivalent of an atomic bomb is 8000 tons with a detonation altitude of 400 meters. The detonation occurs at the lateral rear side of the structure. The distance between the structure and the projectng

10

point R' of the detonation center is 400 meters. Calculation is required to check the structure's capability of defense against gamma radiation.

1. Consideration is given to the incident dosage of gamma radiation on the air detonation effect:

The calculation formula: $D_{\gamma o} = AK/R^2$ (7)

In the equation, K is the relationship coefficient of TNT equivalent q; and A is the influence coefficient of photon energy of gamma rays, considering the air detonation density ρ.

From the dosage distribution (Fig. 3) of gamma radiation during atomic detonation of a Hiroshima bomb, we can obtain the following simplified formula:

When $R < R_1$, A=1; when $R_1 \leqslant R \leqslant R_2$; $A = e^{-R/250}$; as recommended in some manuscripts, then $A = e^{-R/300}$.

From the physical concept of studying the function of the shock wave, O. I. Lenpunskiy derived the following equation:

For detonation in the atmosphere: $K = 6.6 \times 10^4 q e^{(0.025\sqrt{q} - 6.25 \times 10^{-4} q)}$ (8)

Simplifying Eq. (8), we obtain $k = 1.4 \times 10^4 q (1 + 0.3 q^{2.66})$ (8')

Then the value of K can be obtained from Fig. 4.

For ground detonation: $K = 2.8 \times 10^3 q (1 + 0.3 q^{0.65})$ (9)

When $R > R_2$, $A = e^{-R/300}$

$$K = 5.5 \times 10^3 q [1 + 0.05 (aq)^{0.8}] \quad (10)$$

Or, we simplify it into $K = 5.5 \times 10^3 q$ (10')

For ground detonation, a=2; for air detonation, a=1. R is the distance from the air defense structure to the detonation center.

$$R = \sqrt{H^2 + R'^2} = \sqrt{400^2 + 400^2} = 565 \text{ meters.}$$

This topic is $R_1 \leqslant R \leqslant R_2 \quad A = e^{-R/300} = e^{-565/300}$

$$= 0.206$$

11

From Fig. 4, we obtain $K=1.8 \times 10^{10}$. The incident dosage

$$D_{\gamma o}=[(1.8 \times 10^{10})/565^2] \times 0.208=10,700 \text{ roentgens.}$$
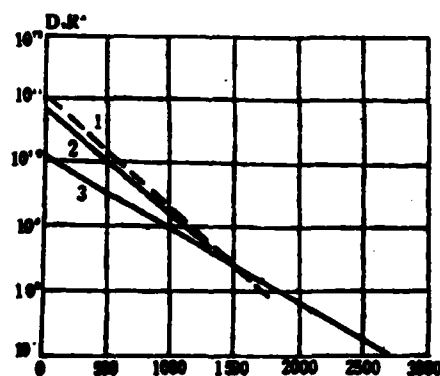
Fig. 3. Experimental data of dosage distribution of gamma radiation during detonation of Hiroshima-type atomic bomb: 1. $\lambda=252$ m; 2. $\lambda=282$ m; 3. $\lambda=393$ m.
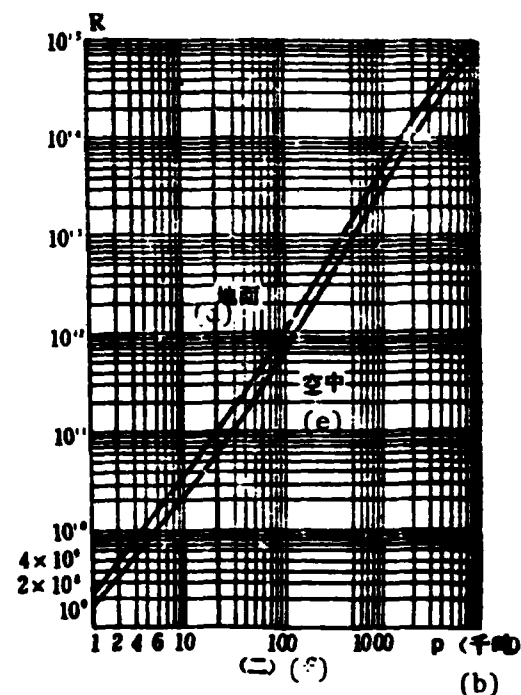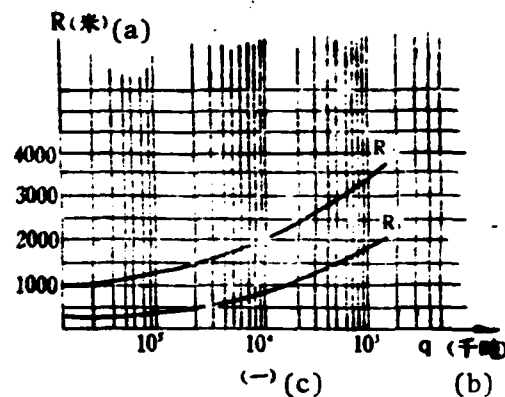
Fig. 4. (1) R_1, R_2; (2) Rq diagram. Key: (a) m; (b) Kilotons; (c) 1; (d) Ground surface; (e) Air; (f) 2.

2. Decayed dosage after gamma rays pass through the roof of an air defense basement

According to the practical situation, the gamma ray incidence acts on an oblique direction. First, the rays pass through the wall of a story, and the story itself; then the rays pass through the cover of the shelter-basement before finally entering it.

Calculation formula: $D_\gamma' = a_\gamma b D_{\gamma 0} 2^{-H_n/d}$ (11)

From Fig. 1, we obtain a_γ=0.95; from Table 4, we obtain (R'/H)=1 and b=0.39.

Converting the 10-cm covered blast furnace slag on the roof of shelter-basement into the equivalent thickness of reinforced concrete

$$H_o' = \frac{x\mu'}{\mu} = \frac{10 \times 0.027}{0.07} = 3.9 \text{ cm.}$$

The wall of two-brick thickness is converted into the equivalent thickness of reinforced concrete $H_w'' = [(49 \times 0.05)/0.07] = 35$ cm.
Since the gamma rays are of oblique incidence, the wall thickness
$$H_{n3} = (35/\cos 45°) = 49.5 \text{ cm.}$$
In this example, a six-story building is above the shelter-basement; it is possible that gamma rays may pass through five floors before reaching the basement roof. Therefore, the total thickness is
$$H_w = 10 \times 5 + 3.9 + 30 + 49.5 = 133.4 \text{ cm}$$
(Note: the thickness of a story floor is 10 cm, and the thickness of the basement roof is 30 cm.)

Decayed dosage: $D_\gamma^n = 0.95 \times 0.39 \times 10700 \times 2^{-133.4/10} = 0.38$ roentgens.

3. Dosage of decayed gamma rays after passing through a wall

Calculation formula: $D_\gamma^{CT} = a_\gamma b D_{\gamma 0} 2^{-H_{CT}/d}$ (12)

Usually, a wall of an air defense shelter-basement is situated below the ground surface; only a wall of a semi-basement and pile-up type air defense works is exposed to the ground surface. In this example, this portion is neglected.

4. Decay of gamma rays due to hole opening

13

a. We calculate the incident radiation dosage according to the theory of angular distribution

As revealed by experiments, when a portion of the radiation dosage is hindered by a shielding body, the incidence of rays on a detector is only the gamma rays exiting from a scattered medium within a certain three-dimensional angle; this leads to the problem of angular distribution of radiation. It follows that the incident gamma rays onto a hole opening can also be considered as incidence at a definite three-dimensional angle.

Calculation formula: $$D_{n} = D_{n\theta} \cdot F(\theta) \cdot \Omega \qquad (13)$$

As recommended by related manuscripts, the function of angular distribution of the scattered intensity of gamma rays in the air due to fission fragments can be written as:

$$F(\theta) = K_{\theta}'[0.0092 + 3.22e^{(-0.0000)}] \qquad (14)$$

The dosage angular distribution of the captured gamma radiation is subject to

$$F(\theta) = K_{\theta}(0.006 + 2.11e^{(-9.0000)}) \qquad (15)$$

$F(\theta)$ is the proportion of the constituent of the dosage (in the total dosage) in a unit three-dimensional angle in the direction of the scattered angle of the constituent. θ is calculated from the source to the connecting line with the detector.

K_{n} is the unitary coefficient, related to α (the intersection angle between the ground surface and the direction of the detonation center) and earth's reflectivity. $K_{\theta} = \dfrac{\overline{K}_{\theta}}{1 + A_{\gamma\theta}(\alpha)}$

$\overline{K}_{n}$ is the unitary coefficient of the assumed black medium (for earth) without reflection of gamma radiation.

$A_{\gamma o}(\alpha)$ is the integrated reflectivity of the earth to gamma radiation when the orientation angle of the detonation point is α.

A major portion of the captured gamma radiation has been reflected within 0.1 second; its function actually comes to an end within 0.3 second following

14

detonation. In this duration, actually the radioactive cloud has not risen; therefore, the source of the captured gamma radiation can be considered as a stationary source like the source of neutrons.

The dose rate of fragment gamma radiation varies with time; the dose rate is determined by three factors: radioactive decay of the fragments, rising of radioactive cloud, and a vacuum chamber formed by the shock wave in the atmosphere.

The dosage of gamma radiation within a unit three-dimensional angle is:

$$D(\theta,\varphi) = \frac{\int_{0}^{t_0} K_b'(t)[0.0002 + 3.22e^{-0.00t(t)}]u(t)K_r(t)K_g(t)dt}{\int_{0}^{t_0}u(t)K_r(t)K_g(t)dt} \qquad (16)$$

However,

$$\theta(t) = \arccos\left[\sin\left(\arctan\frac{H + 16t^2}{\sqrt{R^2 - H^2}} - \epsilon\right)\sin\theta\cos\varphi + \cos\left(\arctan\frac{H + 16t^2}{\sqrt{R^2 - H^2}} - \epsilon\right)\cos\theta\right] \qquad (17)$$

This equation is too cumbersome in application. In order to satisfy the engineering application, the author proposes to use the following formula.

Calculation formula: $\qquad D_{\gamma n} = D_{\gamma 0}\eta_\gamma\Omega \qquad (18)$

In the equation, $D_{\gamma n}$ is the radiation dosage (in roentgens) entering the hole opening; when $\eta_\gamma - \Omega \approx 1$, the ratio between the radiation dosage entering the hole opening and the total radiation dosage can be obtained from Fig. 5. Ω is the three-dimensional angle of the hole opening ($\Omega \approx \alpha/r^2$); a is the cross hatching of the three-dimensional angle of the hole opening; and r is the radius (in centimeters) of the three-dimensional angle.

For the example given before, the calculation procedures are explained as follows:

15

Due to rising of the radioactive cloud following detonation of an atomic bomb, at any instant the orientations of the three-dimensional angle and the detonation center vary; i.e., the intersection angle $\phi'=\phi_1+90°$ (ϕ_i is the instantaneous incident angle). We know from the diagram that once the intersection angle ϕ' varies, the ratio η_γ also varies.
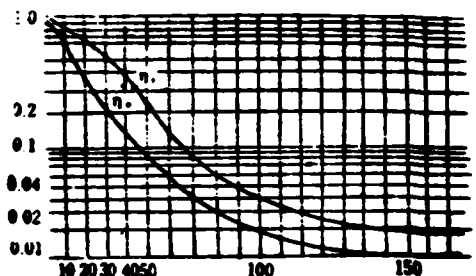

Fig. 5. Ratios between the radiation dosage entering the hole opening and the total radiation dosage at the outer layer of the works.

According to conditions for this example, when radiation is 0-20 percent, $\phi'=45°+90°=135°$ and $\eta_1=0.017$; when radiation is 20-40 percent, $\phi'=135°$ and $\eta_2=0.017$; when radiation is 40-60 percent, $\phi'=44°+90°=134°$ and $\eta_3=0.019$; when radiation is 60-80 percent, $\phi'=40°+90°=130°$ and $\eta_4=0.020$; and when radiation is 80-100 percent, $\phi'=32°+90°=122°$ and $\eta_5=0.022$.

$$\Omega = s/r = 2 \times 180 + 2 \times 110 + 400^2 = 0.058$$
$$D_\eta = 10700 \times 0.058(0.017 + 0.017 + 0.019$$
$$+ 0.020 + 0.022)/5 = 11.79 \text{ (roentgens)}$$

b. The incident radiation dosage calculated on the decay coefficient

The gamma rays transmitted to the underground works from the detonation center move along straight lines; the rays should be turned 90° through the hole opening, thus weakening the radiation dosage. There are differences in decay coefficients in different papers; as recommended by the INTRODUCTION TO NUCLEAR BOMB DEFENSE (published in the United States), the radiation may be weakened by 0.07 fold; in some papers, it is suggested that the radiation may be weakened by

16

0.25 fold. This is because the radiation is further weakened when entering into a horizontal passage due to different cross sections of the passage and the inlet opening. This weakening function of the radiation is generally called as additional function or area function. The transmission coefficient AF_a of the area function can be expressed by the following equation.

AF_a=(area of horizontal inlet opening)/(cross-sectional area of horizontal passage)   (19)

When radiation enters the underground air defense structure from a horizontal passage, there is similarly an area function, as expressed by the following formula:

AF_a'=(cross-sectional area of horizontal passage)/(cross-sectional area of the shelter basement)   (20)

It is apparent that radiation intensity is weakened from passing through a protective door. As sufficient data are not available, the author proposes for the time being to take 0.92 as the transmission coefficient; i.e., the radiation intensity $D_{\gamma 3}$ of gamma radiation after passing through a protective door.

$D_{\gamma 3} = D_{\gamma 0} \times AF_a \times AF_a' \times$(transmission coefficient of turn)x(transmission coefficient of the door)

According to the conditions of this example, the calculation proceeds as follows:

Known quantities: cross-sectional area of inlet, 90x160;
        cross-sectional area of the passage, 200x240; and
        cross-sectional area of the shelter basement, 240x600 (indicating one
            room of the shelter-basement).

        i. We now consider that there are three 90° turns; the incident dosage is: $D_{\gamma 3}' = 0.07^3 \times 10700 = 3.67$ roentgens.

        ii. $AF_a = (1.0 \times 1.7)/(2.0 \times 2.4) = 0.35$.

        iii. $AF_a' = (2.0 \times 2.4)/(2.4 \times 6.0) = 0.33$.

17

iv. The decayed radiation dosage after passing through 10 cm of reinforced concrete

$$D_{r3}'' = a_r \times D_{r3}' 2^{-k/40} = 0.95 \times 3.67 \times 2^{-10/40} = 1.75 \text{ roentgens.}$$

The incident dosage of the hole is:

$D_{\gamma3} = D_{\gamma0} \times AF_a \times AF_a' \times$ (transmission coefficient of turn) $\times D''_{\gamma3} = 10700 \times 0.35 \times 0.33 \times 0.07^3 + 1.75 = 2.17$ roentgens.

v. Dosage of gamma radiation entering the shelter-basement:

D =0.38+11.79+2.17=14.34 roentgens.

IV. Calculation for Defending Against Neutron Stream by an Air Defense Structure

1. Calculation of incident dosage D_{no} of neutron stream

$$D_{no} = (m/R^2)(e^{-R/250}) \text{ (biological roentgen-equivalent)} \qquad (19)$$

In the equation, m - is the decided upon coefficient of

A-bomb equivalent which is employed according to Fig. 7.

$$D_{no} = \frac{4 \times 10^9}{565} e^{-565/250} = 12500 \quad \text{(biological roetgen equivalent)}$$

2. Calculation of the decayed dosage after passing through the roof of shelter-basement with consideration of oblique emission of neutron stream

Calculation formula: $D_n = a_n D_{no} 2^{-H_n X / d_n \cos \phi}$ (20'

In the equation, D_n is the dosage after a neutron stream passes through the roof of shelter-basement with thickness (of roof) of $H_n X/\cos \phi$; d_{no} is the half-value thickness of the neutron stream, obtained from a table; and a_n is the decay coefficient for neutrons with consideration of a medium surface, obtained from Table 8.

a. The story floor, wall and blast-furnace slag are converted into equivalent values of thickness of reinforced concrete.

For 10-cm blast furnace slag: $H'_{n3} = (10 \times 9.7)/(11.6) = 8.4$ cm;
for wall: $H'_{n3} = (49 \times 12)/(11.6) = 50.7$ cm; and
for story floor: $H'''_{n3} = 5 \times 10 = 50$ cm.
The roof of shelter-basement is 30 cm thick. Total thickness (of cover):
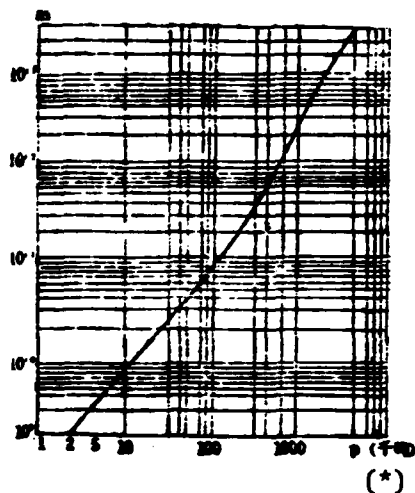$H_n = 8.4 + 50.7 + 50 + 30 = 139$ cm.

Fig. 7. q∿m diagram.
Key: (*) Kilotons.

Table 8.

(a)材料名称	(b) dan 半值衰减厚度	an
(c) 土壤、钻砌体	12	0.7
(d)混凝土	11.6	0.6
(e)钢 铁	6	0.25

Key: (a) Material; (b) Thickness of half-
value decay; (c) Soil, dressed masonry; (d)
Concrete; (e) Iron or steel.

b. $\cos\phi = \dfrac{400}{\sqrt{400^2 + 400^2}} = 0.71$

c. Decayed dosage: $D_{si} = 0.6 \times 12500 \times 2^{-120/6.71\times11.6} = 0.062$

(biological roentgen-equivalent)

2. Calculation of decayed dosage after passing through a wall with considera-
tion of oblique emission of neutron stream:

Calculation formula: $D_{cd} = a_c D_{cd} 2^{-8 cn} \cdot \sin \phi \cdot \phi_c$ (21)

Since the shelter-basement is situated below the ground surface, this portion of incident dosage is neglected.

3. Decayed dosage of neutron stream entering a hole opening

    a. Dosage of neutron stream entering through a door opening calculated with consideration of angular distribution:

Calculation formula: $D'_{cd} = D_{cd} q_c \Omega$ (22)

(To be continued on back cover of text)

[Figure 6 and Table 7 are missing; they may be in the last portion of text that was missing. Translator's note]

(Continuation from text page 32)

It is now assumed that the vertex of the three-dimensional angle is located at the midpoint of two passages, assuming that r=120 cm and the included angle $\phi'=135°$. From Fig. 5, $\eta_n=0.012$, s=2x100+2x180=580 cm, and $\Omega=(580/120^2)=0.04$.

$D'_{n3}=12500\text{x}0.012\text{x}0.04=6$ (biological roentgen-equivalent)

(b) Dosage of decayed neutron stream after passing through the protective door

Calculation formula: $D_{n2}=a_n D'_{n3}\cdot 2^{-h/d}{}_n = 0.6\text{x}6.0\cdot 2^{-10/11.6} =1.98$

(biological roentgen-equivalent)

4. Total dosage of neutron stream entering the basement shelter

$D_n=0.062+0+1.98=2.042$ (biological roentgen-equivalent)

5. As derived from the aforementioned steps, it is required that the summation of the remaining total dosage of gamma rays and neutron stream should not exceed the allowable dosage, 50 roentgens.

That is, $D=D_\gamma+D_n=14.34+2.042=16.382$ [50]

V. Characteristics in Calculating Penetrating Radiation After Detonation of a Thermonuclear Weapon

As mentioned above, the existence of ultrafast neutrons is a characteristic of penetrating radiation upon detonation of a thermonuclear weapon. For various types of hydrogen bombs, gamma rays still occupy the major portion of the radiation; generally, fast neutrons and ultrafast neutrons do not occupy a major portion. The following formulas are used in calculation:

Dosage of gamma rays: $D_\gamma=(4\text{x}10^{13}/R^2)\cdot e^{-R/250}$ (roentgens)   (23)

Dosage of fast neutrons: $D_n=(3\text{x}10^{12}/R^2)\cdot e^{-R/250}$ (biological roentgen-equivalent)   (24)

Dosage of ultrafast neutrons: $D_{ultra}>(4\text{x}10^{11}/R^2)\cdot e^{-R/250}$ (biological roentgen-equivalent)   (25)

VI. Conclusion

Through the above discussion, the authors have formed an understanding of calculation of penetrating radiation defense in fortifications. The following points are listed for the readers' attention to avoid mistakes.

1. In this paper, it is assumed that the ascending speed (of the radioactive cloud following a nuclear detonation) is constant; that is, $H_t = H + \nu_{cp} t$ ($\nu_{cp} = 100$ m/sec). As stated by associate professor Qian Shihu, who quoted a book, Protection Against Neutron Stream and Gamma Radiation in Nuclear Radiation, 1969, written by Kuhetaiweiji [transliteration of Russian name] et al of the Soviet Union that the ascending radioactive cloud has constant acceleration; i.e., $H_t = H + 6t^2$. Since there is no such statement in the recently published literature in the United States and Britain, the constant acceleration of the ascending radioactive cloud is not included (authors' note).

2. In this paper, the ascending radioactive cloud has constant velocity; therefore, the incident dosage is calculated by using Eq. (3). If the ascending cloud has constant acceleration, then the incident dosage is a variable. The value of $D_{\gamma o \cdot i}$ can be derived by integration. Any measured data can be used directly.

3. When the consideration is given that the ascending radioactive cloud has constant acceleration, data in Tables 4 and 5 can still be used as an approximation, the authors will compile blank forms of the oblique-direction decay coefficient of the protective layer.

As the authors have small scientific learning with limited level, mistakes naturally exist in the paper. The authors welcome corrections from experts, scholars and readers.

LITERATURE

1. O. N. Lieyipengsiji [transliteration of Russian name] (translated into Chinese by Tang Bi), Gamma Radiation of Nuclear Detonation, China Industry Publishing House, 1963.

2. Chen Shuhui, Calculation of Horizontal Protection Layer by Weakening the Penetrating Radiation, Renmin Gongbing [People's Engineering Corps], 1963, Supplement Issue No. 33.

3. J. R. Lamarhi, Introduction to Nuclear Engineering, London, 1975.

4. A. Edwardprofio, Radiation Shielding and Dosimetry, New York, 1979.

5. Kang Ning, Fortification Calculation in Defense of Penetrating Radiation, Renmin Gongbing [People's Engineering Corps], 1963, Supplement Issue No. 33.

END

FILMED

5-84

DTIC